FRED Reports

Glacial Silt - Help Or Hindrance
To Lake productivity

by
J. P. Koenings, J. A. Edmundson,
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Number 93

Alaska Department of Fish & Game
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Don W. Collinsworth
Commissioner

Brian J. Allee, Ph.D.
Director

P.O. Box 3-2000
Juneau, Alaska 99802-2000

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ABSTRACT

Residents of the city of Haines expressed concern over the effect of the periodic influx of cold, turbid water from the Tsirku River on the sockeye rearing capacity of the clearwater Chilkat Lake. Studies on the rearing environments of glacial and clearwater sockeye nursery lakes were used to describe the benefits and the risks of glacial silt. It was determined that turbidity levels <5 NTU could serve as an empirical point were potential benefits outweighed risks. In addition, comparisons of the zooplankton and sockeye smolt populations of Chilkat and statewide glacial lakes suggest that the intrusions of turbid, cold water of the Tsirku River have not caused Chilkat Lake to reflect exceeding the 5 NTU barrier. This analysis serves as a prime example of how information gathering leads to discovery of patterns in nature which in turn leads to public benefit.

<u>Key Words:</u> Sockeye salmon, glacial, lakes, production, zooplankton, turbidity, silt, temperature.

STATEMENT OF CONCERN

Public concern about detrimental changes occurring in the rearing capacity of Chilkat Lake for juvenile sockeye salmon (*Oncorhynchus nerka*) arises because of the periodic intrusion of turbid glacial water into the lake from the Tsirku River. The latter phenomenon occurs when snow melt and seasonal rains combine with glacial-melt water to increase the discharge of the Tsirku River to the point of intruding into the lower portion of Chilkat Lake (Figure 1). When the high flow of the Tsirku River merely backs up the outflow of Chilkat Lake, the intrusion of cold, turbid water reaches about 0.8 km into Chilkat Lake. However, when events combine to force a portion of the Tsirku River to actually flow across the shallow Chilkat Lake delta into Chilkat Lake, the intrusion extends for a distance of ~3.2 km. The question has been raised of the effect, in particular, of the latter scenario on the rearing capacity of Chilkat Lake proper.

BACKGROUND

Lake Size in Relation to Productivity

Essentially, two factors bear on the relative capacity of nursery lakes to successfully rear sockeye salmon juveniles namely: size and in-lake productivity. That is, a large lake with lowered productivity (fry rearing capacity) when compared to a somewhat smaller system having a larger productivity could produce or support equivalent numbers of rearing fish. Recognizing these differences is important as stocking densities for juvenile salmonids have traditionally been based solely on surface area. The obvious problem with this approach is that only one of the two factors was considered i.e., size of lakes. Glacial lakes, as defined by receiving turbid meltwater from glaciers, are located throughout Alaska,

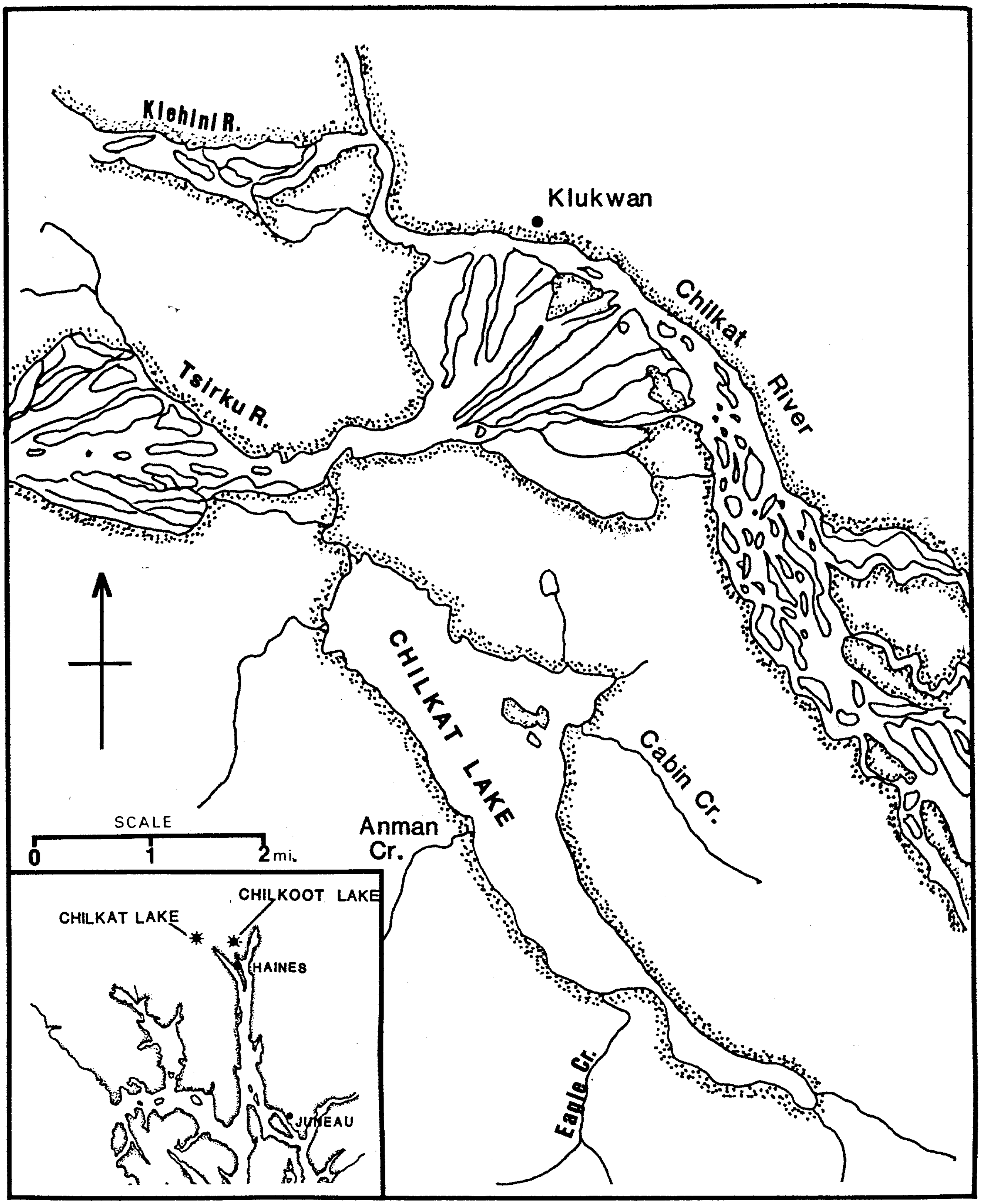

Figure 1. The relationship of Chilkat Lake to the Tsirku and Chilkat Rivers (after Anonymous 1960).

yet have received little attention relative to the affects of glacial silt or flour on basic autochthonous (in-lake) productivity. Many of these lakes support large and valuable runs of adult sockeye salmon (e.g., Tustumena, Kenai and Skilak in Cook Inlet, Miners in Prince William Sound, Chilkoot, Crescent in northern Southeast). Productivity differences between glacial and non-glacial lakes was harder to derive, especially for differences that could be quantitatively used to correct lake surface area for fish yield projections.

Primary Production and Fish Yield

As Foerster (1968) points out "Since the production of zooplankton (sockeye forage) depends on the abundance of phytoplankton and this, in turn, on the quantities of inorganic substances and on favorable conditions for rapid and extensive photosynthesis, a thorough study of primary production in sockeye producing lakes is of paramount importance. Despite its importance, however, in the consideration and evaluation of a lake as a food-producing unit for young sockeye and its intimate role in the food-chain, phytoplankton production has been thus far, but cursorily studied in sockeye lakes." Since the driving force for photosynthesis is solar radiation and since nutrient concentrations in Alaskan sockeye lakes fall in a very narrow range i.e., oligotrophic,; Koenings and Burkett (1987) for the first time derived a correction factor for sockeye smolt production based upon light penetration. The greater the euphotic zone depth (EZD), the greater the volume in which photosynthesis occurs and the larger the productivity per m^2 of lake surface (Figure 2). Conversely, any decrease in the depth to which 1% of subsurface light penetrates do to abiotic particles lessens areal productivity and smolt yield. Combining depth of light penetration (euphotic zone) with lake surface area yielded a easily determined index to sockeye

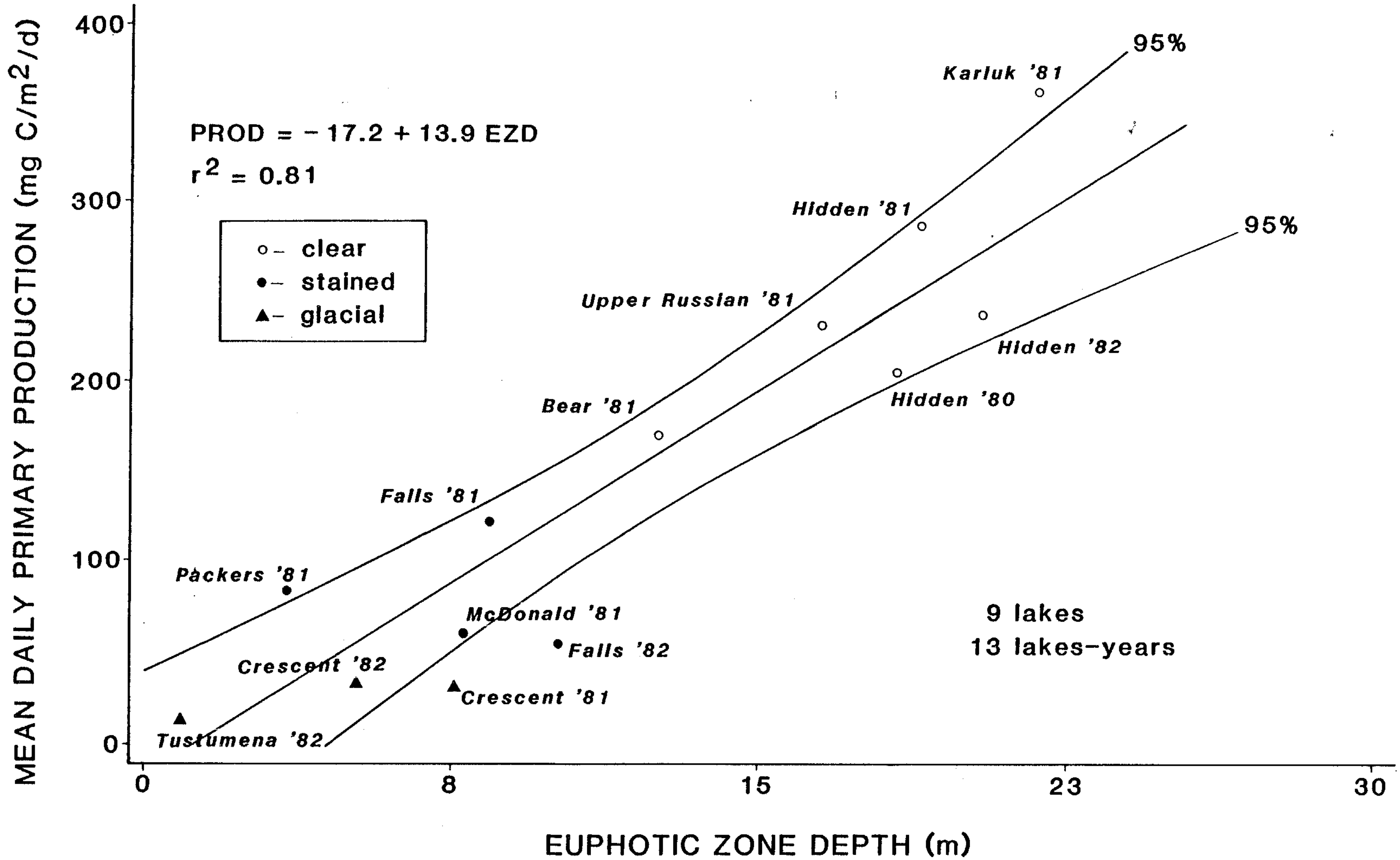

Figure 2. The relationship between areal rates of primary production and the depth of the euphotic zone (EZD) established for clear, stained, and glacial Alaskan lakes (after Koenings and Burkett, 1987).

smolt production that combines in-lake productivity with lake size (Koenings and Burkett 1987).

Photosynthesis by lake phytoplankton has been used as an indicator for potential fish yield (McConnell et al. 1976) and has been used as a correlate to sockeye smolt size (Nelson 1958). In addition, Oglesby (1977) and Jones and Hoyer (1982) used lake phytoplankton as a correlate to fish yield with Hanson and Leggett (1982) using nutrient (phosphorus) levels as a predictor of fish yield. In turn, Dillon and Rigler (1974) offered empirical evidence for a cause and effect relationship between phosphorus levels and lake phytoplankton production.

Phosphorus and Primary Production

Altogether this research has established a strong relationship between primary production and fish yield. In turn, solar radiation (Brylinsky and Mann 1973) and lake nutrients, especially phosphorus, are strong determinants of primary production (Schindler 1978, Smith 1979). If light penetration decreases because of the introduction of abiotic particles than productivity falls (Koenings et al. 1986; Koenings and Burkett 1987). Such reductions have been documented by Oglesby (1977), Schindler (1978), and Smith (1979) among others for silty reservoirs located in the lower continental United States. Moreover, phosphorus is now regarded as the major nutrient that limits primary production in the world's freshwaters (Schindler 1978). Factors which can modify or uncouple this correlation to a significant extent are temperature and light (Brylinsky and Mann 1973, Bachmann 1980). The point to be made here is: at what point does light reductions and lowered temperatures cause primary production to be uncoupled from nutrient limitation?

ANALYSIS

Turbidity, Phosphorus, and Iron

In our studies of sockeye lakes (e.g., Koenings et al. 1986b), we measured nutrient concentrations as well as light penetration profiles and/or turbidity levels in both turbid and non-turbid systems. From this we found that light penetration in lakes was drastically reduced (Figure 3) at turbidities $\geq$5 NTU (Lloyd et al. 1987). Moreover, we found that the 5 NTU cutoff served as a useful guide to classifying turbid from non-turbid systems. Next, our nutrient studies on glacially turbid Crescent Lake revealed very high seasonal total phosphorus (TP) values that corresponded to seasonal decreases in light penetration (Koenings et al. 1985). Both the decrease in light penetration and increased TP levels are associated with increased turbidity derived from glacial meltwater (Figure 4). Using a chemical extraction technique developed by Koenings et al. (1987a), we determined the amount of particulate inorganic phosphorus entering glacial lakes as part of the glacial flour. This method measures mostly absorbed P and Fe, and Al and Ca phosphate salts (Kuenzler et al. 1979). We found the between 80% and 90% of the total phosphorus present in glacial lakes is inorganic phosphate associated with the glacial particles. In fact, we found excellent agreement between total phosphorus levels and turbidity (Figure 5A) as well as between turbidity and iron (Fe) levels (Figure 5B). Thus, glacial meltwater introduces vast quantities of a nutrient that limits primary production in most of the worlds freshwater lakes.

Sediment Loading Versus Nutrient Enrichment

The question remains of the ultimate availability of this source of inorganic phosphate, and the short versus long term effects of the accompanying sediment. Sediment loading that

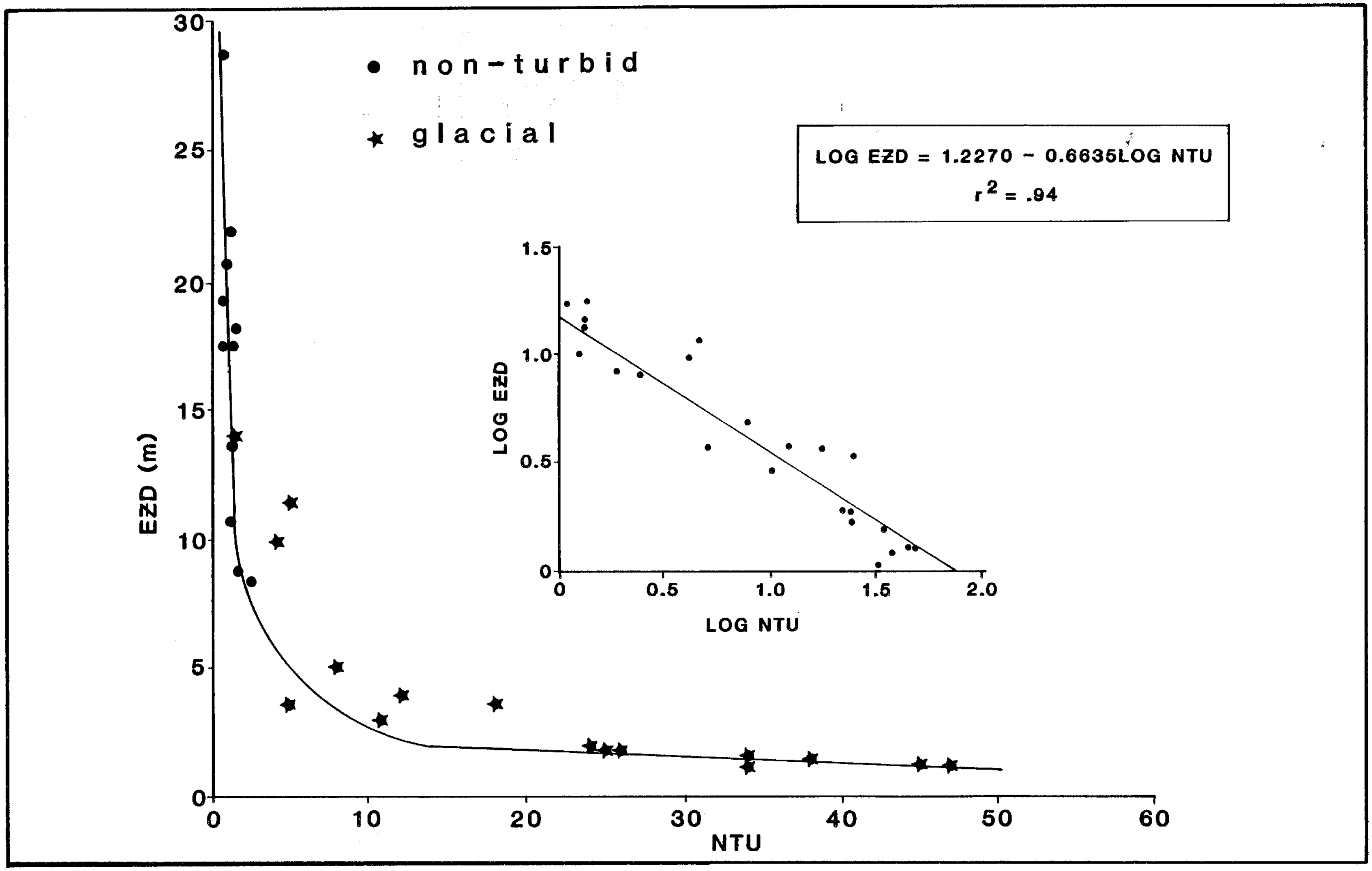

Figure 3. The relationship between euphotic zone depth (EZD) and turbidity for clear, stained, and glacial Alaskan lakes showing the overlap of several glacially influenced systems into the EZD range of non-turbid systems (from Koenings et al. 1987b).

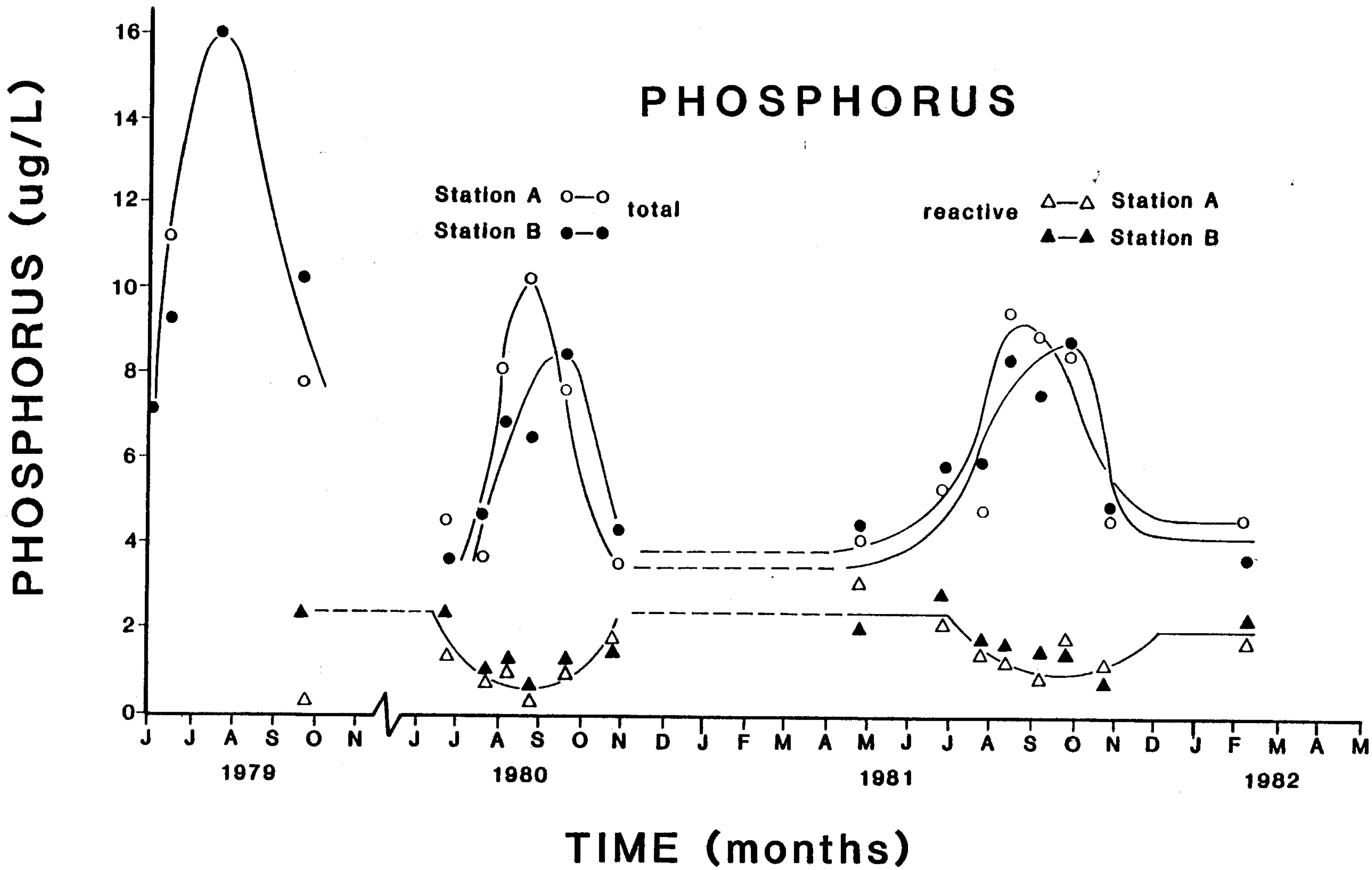

Figure 4. Seasonal profiles of total and reactive phosphorus in the epilimnion of Crescent Lake in 1979, 1980, and 1981 (from Koenings et al. 1985).

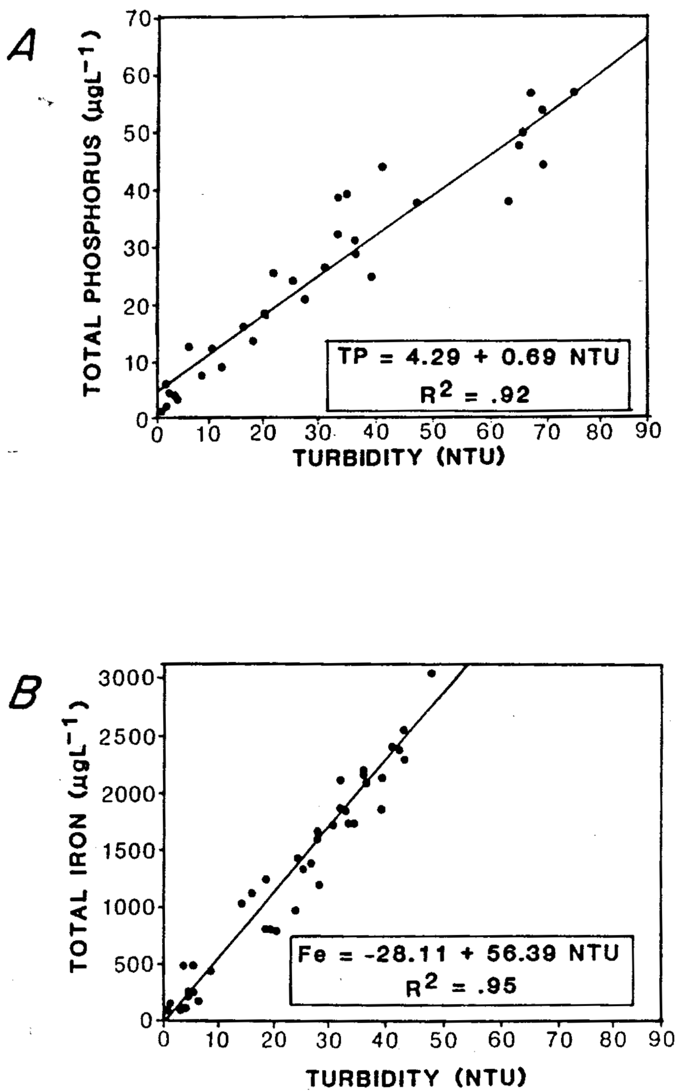

Figure 5. The relationships between (A) total phosphorus concentrations and turbidity; and between (B) total iron levels and turbidity established for clear, stained, and glacial lakes (after Edmundson and Koenings, 1985a).

causes large increases in turbidity can have devastating effects on fishery resources in both streams and lakes of Alaska (Lloyd et al. 1987). Short term effects of heavy ash fall, for example, destroyed fish and fish food organisms following the 1912 eruption of Mount Katmai. Turbid water running off of 10-12 inches of ash fall was responsible for suffocating spawning adult salmon as well as destroying fish food organisms of Afognak and Kodiak Islands (Eicher and Rounsefell 1957). Yet ten years later the runs had rebounded to levels at or exceeding those found before the eruption. Eicher and Rounsefell (1957) attributed this remarkable turnaround to the fertilization of watersheds by ash leachate which contained abundant amounts of phosphorus, magnesium, and calcium. Such fertilization of previously unproductive waters provided abundant fish food organisms that lead to larger smolts and greater adult returns from each successive brood year. Years later on Afognak Island, Dugdale and Dugdale (1971) showed the mechanism by which inorganic particulate phosphorus originally contained in the ash was leached. Differences in the extent of leaching was correlated with the average slope of the watershed with steep watersheds accelerating the rate of phosphate leaching by percolating rainfall.

Other sources of absorbed inorganic phosphate has been shown to be river particulate matter (Wang 1974), and agricultural sediments (Bachman 1980). In such cases, high sediment concentrations were found to deliver nutrients, such as phosphorus, back into the water column maintaining more productive conditions. These observations were experimentally confirmed by Smith et al. (1977) who found that apatite (rock phosphate) crystals could serve as sources of phosphorus for bacteria and algae which in turn provided a food source for grazing zooplankton. They suggested, moreover, that the contribution of inorganic phosphate from apatite could be an important source of this limiting nutrient in oligotrophic lakes. As such, glacial silt can provide a long term positive source for a nutrient that enhances lake productivity, but at the same time can have a negative impact on light penetration which serves to lessen lake productivity.

Temperature, Zooplankters, and Sockeye Smolt Sizes

Mayo (1986) found that glacial melt-water may contribute up to 75% of the annual water recharge of glacial lakes. Added to this large input of cold, turbid water is the increased reflection or backscattering of incident light concomitant with increased turbidity that further lowers in-lake temperatures (Hecky 1984; Koenings et al. 1986). Thus, the surface temperatures of glacial lakes tend to be significantly cooler than those of non-turbid lakes (Figure 6).

Because of the lowered primary production and temperatures, glacial lakes tend to exhibit lower densities of macro-zooplankters (Koenings et al. 1986). Beyond the indirect effects of turbidity on zooplankton, the silt itself appears to interfere with the ability of filter feeding cladoceran (e.g., *Daphnia* and *Bosmina*) zooplankters to extract sufficient energy from ingested food to survive and reproduce (Edmundson and Koenings 1985b). Thus, the zooplankton community of glacial lakes is different from that of non-turbid lakes (Table 1) in that copepods (*Cyclops* and *Diaptomus*) are typically the only detectable macro-zooplankters. Copepods are non-preferred prey items for foraging sockeye juveniles compared to cladocerans, and in Alaskan lakes copepods tend to produce a single pulse of adults in a season.

Finally, in response to the effects of turbidity on light regimes, rearing sockeye juveniles in glacial lakes exhibit a diel vertical migration pattern reverse of that found to occur in clear lakes. Low light levels also decrease the feeding efficiency of visual feeding sockeye juveniles. Thus,

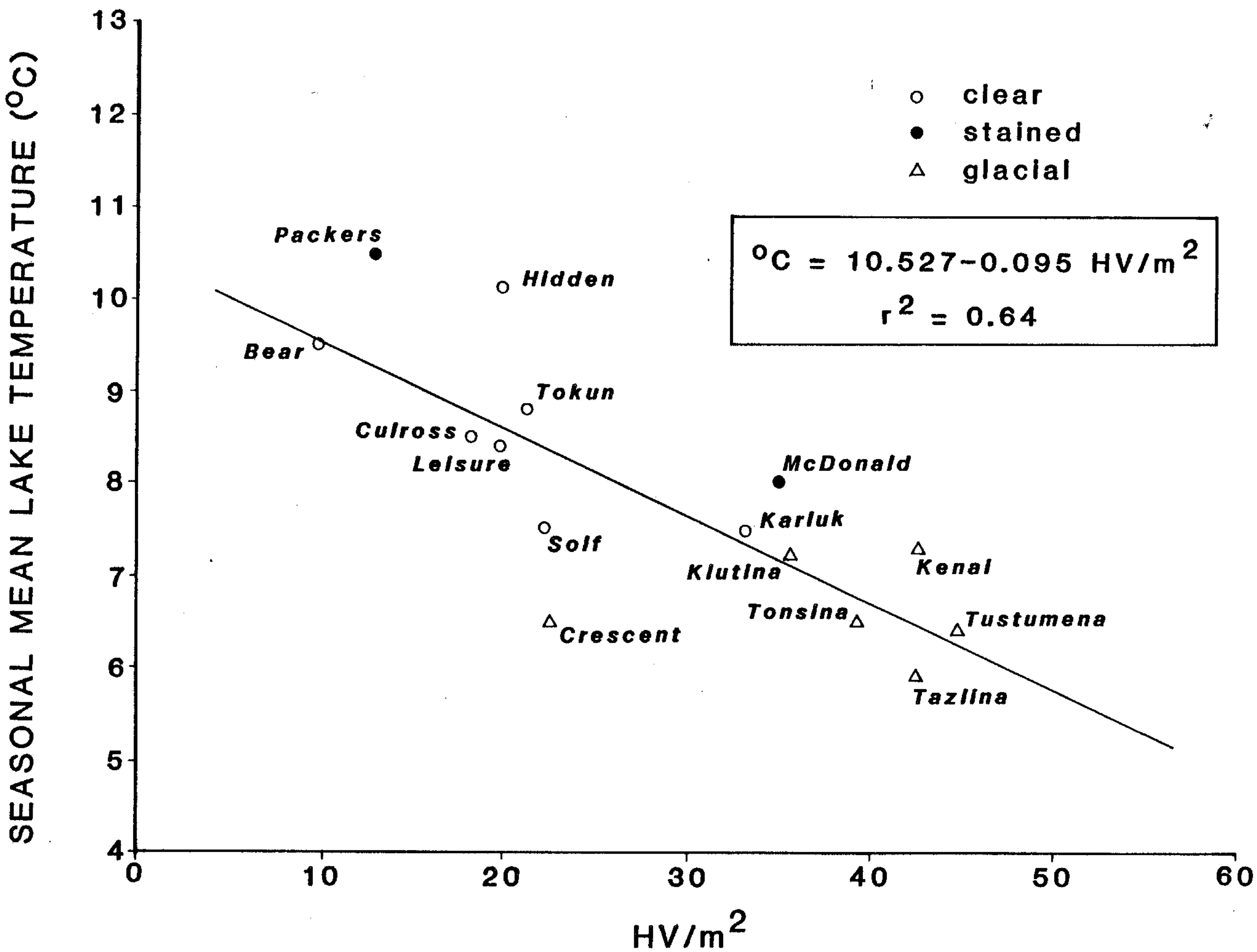

Figure 6. The relationship between seasonal mean lake temperature (°C), and the ratio between heated volume (HV) and surface area for clear, stained, and glacial lakes.

Table 1. Comparison of zooplankton community composition (May-November) between glacial (5 NTU) and non-turbid (5 NTU) lakes. Represented lakes are examples taken from a more complete data set (18 turbid and 78 non-turbid lakes) that includes lakes located throughout Alaska. Relative densities are represented by: absent (-), 33% (+), 34% to 66% (++), and 67% (+++) (after Koenings et al. 1986).

	Glacial (>5 NTU) lakes								Non-turbid (<5 NTU) lakes						
Taxa/Lake	Tustumena	Kenai	Crescent	Grant	Ptarmigan	Crescent	Miners	Kushtaka	Bear	Upper Russian	Hidden	Packers	Leisure	Karluk	Badger
Cladocera:															
Bosmina sp.	-	-	-	-	-	-	-	-	++	+	+	+	+++	+	+
Daphnia sp.	-	-	-	-	-	-	-	-	++	+	+	+	+	+	+
Holopedium gibberum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Alona sp.	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Polyphemus pediculus	-	-	-	-	-	-	-	-	++	-	-	-	-	-	+
Copepoda:															
Cyclops sp.	+	++	+	++	++	+++	++	++	-	+++	+	+	+	+++	+++
Diaptomus sp.	+	+	-	-	++	-	_	-	-	-	+	++	+	+	+
Epischura sp.	-	-	-	-	-	-	-	-	+	-	+	+	-	-	-
Rotifera:															
Kellicottia longispina	+	+	+	+	+	+	+	+	+	+	++	-	-	-	+
Asplanchna sp.	-	-	+++	+	-	-	-	+	-	-	-	-	-	-	-
Keratella sp.	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Conochiloides sp.	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-

foraging takes place at low light levels on a dilute prey that rearing juveniles have a difficult time catching. In response to the rearing environment (lowered prey abundance and preference, and colder temperatures) in glacial lakes, sockeye smolts are consistently small ($P=.01$; F-test) compared to the range found for clear and stained systems (Table 2). In fact, smolt sizes just exceed the minimal or threshold size found for sockeye (Koenings and Burkett 1987).

The Turbidity Continuum: Benefits and Risks

The point to establish is the position on the turbidity continuum that favors the positive benefits and reduces the risk of the negative influences. Our research findings on glacial lakes (Koenings et al. 1986, Lloyd et al. 1987) lend themselves to establishing this point although funding has not been available to study its application directly to Chilkat Lake. However, nutrient (nitrogen and phosphorus) levels in the lake in October 1980 characterize the lake as oligotrophic (TP = 3 to 4 ug/L). As such the algal nutrient phosphorus appears to be limiting primary production as levels are low and phosphorus to nitrogen ratios are high (Vollenweider 1976). If these conditions are present throughout the growing season, phosphorus levels dictate primary production levels (Edmundson and Koenings 1985a). Moreover, we have established for Alaska clear water lakes a good, strong relationship between seasonal TP levels and primary production measured by the algal pigment chlorophyll a (Figure 7). Notice that several points lie outside the 95% confidence interval defined for the clear systems (N=78, data points for the clear water lakes are not included for clarity of presentation). These indicated points represent glacial systems. That is, light limitation due to increased turbidity has reduced the chl a response per unit of phosphorus e.g., phosphorus no longer controls algal biomass levels. However, a few glacial lakes fall within the range established for light penetration and

Table 2. Representative mean length and weights of sockeye smolts from clear, organically stained, and glacial lakes located throughout Alaska. Values were obtained over the entire outmigration period, but are not number weighted means from total counts (after Koenings et al. 1986).

		Age 1		Age 2	
Lake	Geographic region	Length (mm)	Weight (g)	Length (mm)	Weight (g)
Clear					
Big	Cook Inlet	132	25.5	166	48.1
Hidden	Cook Inlet	143	27.3	200	83.9
Larson	Cook Inlet	86	5.1	123	16.5
Leisure	Cook Inlet	80	4.0	97	9.0
Tokun	P.W.S.	72	2.5	---	---
Eshamy	P.W.S.	76	3.4	101	7.8
Karluk	Kodiak	101	10.7	113	14.1
Frazer	Kodiak	76	3.1	103	7.9
Chilkat	Southeast	98	---	110	---
Stained					
Packers	Cook Inlet	97	8.5	132	21.2
Hugh Smith	Southeast	69	2.9	78	4.4
McDonald	Southeast	70	2.6	79	4.5
Glacial					
Tustumena	Cook Inlet	69	2.7	83	4.5
Crescent	Cook Inlet	68	2.8	76	3.8
Kenai	Cook Inlet	62	2.1	72	3.1
Tazlina	P.W.S.	72	---	73	---
Klutina	P.W.S.	64	---	72	---
Tonsina	P.W.S.	64	---	64	---
Chilkoot	Southeast	63	---	70	---

P.W.S. - Prince William Sound

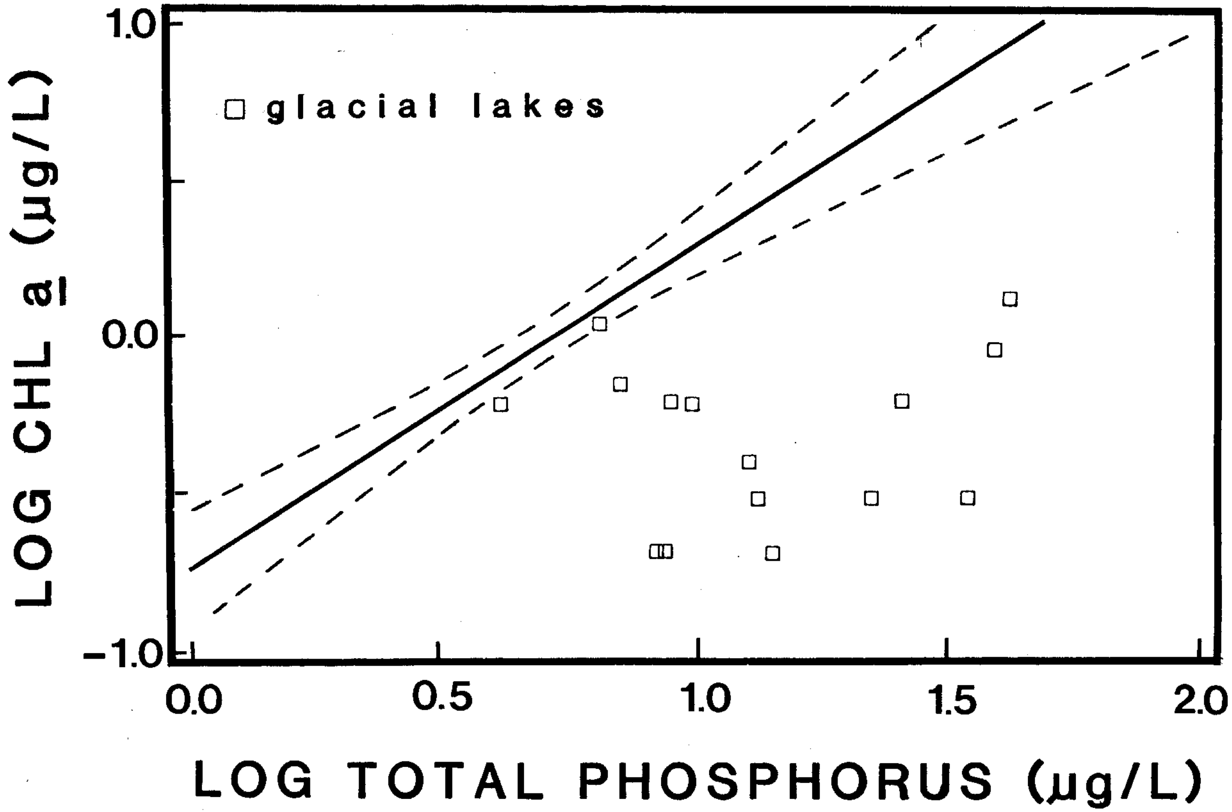

Figure 7. The relationship between total phosphorus concentrations (TP) and the algal pigment chlorophyll a after log transformation of the original data. The regression line ±95% confidence intervals represents clear water systems (actual data points are not shown) with the data points indicated representing glacially influenced systems.

algal biomass established for non-turbid systems (Figures 3 and 7), respectively. The difference being that turbidity levels in these systems are not sufficient to uncouple the nutrient dependence of primary production i.e., they behave as clear water systems. We have determined, for oligotrophic systems, that turbidity levels > 5 NTU uncouple the dependence of algal biomass from nutrient levels, and light increasingly becomes a limiting factor. Thus, the point where the turbidity from glacial silt becomes a risk factor is when system wide turbidity levels exceed 5 NTU. Below this turbidity threshold, the leachable phosphorus in the glacial silt could add up to 7.5 ug/L of phosphorus to the lake water. Other benefits to the lake include significant amounts of calcium and/or magnesium carbonate from the marble rocks common in the Tsirku channel above the lake (Figure 1). As such, minor periodic flooding of the Tsirku may provide a basis for sustaining elevated alkalinities and conductivities in the lake proper (Bishop 1984). Thus, like volcanic ash, glacial silt contains significant amounts of leachable particulate inorganic phosphorus, calcium, and magnesium; and, in a manner similar to volcanic ash, the benefits may lead to increased fish production. The benefit of glacial silt to lake systems, as an enrichment factor, is only reduced when turbidity levels reach or exceed 5 NTU.

SYNOPTIC CASE HISTORIES

<u>The Nile River: An Analog to Glacially Turbid Rivers?</u>

I can add one analogy and two case histories. The analogy is as simple as it is complex: the periodic flooding of the Nile River (Egypt) that enriched the flood plain farm lands of the Nile valley. Once the Aswan High Dam was built the periodic flooding ceased, and the farm lands became nutrient poor and salty. To compensate for the loss of crop yields, the

Egyptian government had to install a fertilizer factory which used much of the electricity produced by the dam to make inorganic fertilizers for the farmers fields. Next, the sardine fishery which was the best in the world prior to the dam's construction collapsed. The nutrients once contained in the Nile River flood waters supported the food chain for this immense fishery off the Nile delta in the Mediterranean Sea. It is no more. A corollary exists for Alaska. Periodic flooding of backwaters or sloughs along the glacially turbid rivers (e.g., the Susitna or Taku Rivers provide yearly inputs of nutrients to these typically clearwater quiet backwaters. Phosphate leaching from the accumulated silt supports luxury growths of periphytic algae during the subsequent spring prior to new flooding. Larvae of various insects (e.g., chironomids) depend on this seasonal blooming for food and, in turn, the larvae and adult insects serve as a food base for rearing salmonids. Only the productive sloughs, not the unproductive main channels, act as significant rearing grounds for Susitna or Taku Rivers salmonid juveniles.

Coghill Lake (Prince William Sound)

The first case history involves our study on a sockeye producing lake in Prince William Sound (PWS) known as Coghill Lake. It is by far the best sockeye producing system in PWS. It is also glacially influenced. I say influenced because while the glacial tinge is there, the turbidity is $\leq$5 NTU. The important difference between this lake and other lakes is that the lake contains a permanent non-mixing layer of dense water beginning at 60 m and extending to the bottom. This layer contains huge reserves of inorganic phosphate derived from glacial silt and decomposed algal cells that become trapped in the stagnant water after death. In more typical lakes, during lake overturn in the spring these regenerated nutrients are returned to the surface as the lake mixes from top to bottom. It is this spring mixing that in large part provides the nutrients necessary for the summer season's primary production. In Coghill Lake this process does not occur. Instead, nutrient inputs are derived solely from the watershed and from phosphate leached from glacial silt. Such inputs of silt account for 50% of the phosphorus entering the lake per year and as such are responsible for supporting a large proportion of the lake's annual productivity. Without this source of phosphorus, Coghill Lake would regress to an ultra-oligotrophic state much like the non-turbid Redoubt Lake in NSE. Redoubt Lake also contains a non-mixing bottom layer that traps nutrients preventing them from returning to the lighted upper waters. To correct this nutrient deficiency at Redoubt Lake, FRED Division is currently fertilizing the upper stratum of lake water.

Robe Lake (Valdez)

The second case history involves a detailed study of the water quality characteristics of Robe Lake, Valdez, that was conducted under the U. S. Environmental Protection Agency's, Clean Lakes Program (Koenings et al. 1986a). Years ago local citizens became concerned over the flooding of Robe Lake, the area's only freshwater lake, during periodic high water conditions of the nearby Valdez Glacier stream. To prevent this from occurring, the people constructed a simple earthen dike or dam. Subsequent to the dike's construction the people of Valdez became alarmed when they began to notice changes in Robe Lake. The first noticeable change was the loss of Robe River as a navigable body of water. Second, the lake which had been silty, cleared, and warmed up. Third, minor amounts of lake vegetation, which heretofore had allowed excellent boating, became excessive and now tangled propellers and hindered swimmers. Fourth, within a period of ten years, the lake began to noticeably shrink (dewater) and the shoreline became less defined. Thus, the residents of Valdez were seeing the only freshwater lake in the area become unusable.

The indirect cause of these rapid changes in the conditions of Robe Lake occurred because of an event in 1956. This is when the stream bed of Valdez Glacier Stream changed its course to enter Corbin Creek and subsequently Robe Lake. In order to stop flooding in the Robe Lake area and to protect the Richardson Highway, the City Fathers constructed a dike on Corbin Creek thereby turning the flood of Valdez Glacier Stream, and also rerouting the primary tributary to Robe Lake (Corbin Creek) out of the Robe Lake watershed.

The short term benefits of this diversion were to reduce flooding, change Robe Lake from a cold, turbidity lake to a warmer, clear lake (much to the enjoyment of swimmers), and to reduce the flow of glacial silt into Robe Lake. However, it is now apparent that the cold turbid water, carried during the summer months by Corbin Creek, had served the dual purpose of cooling Robe Lake and retarding the growth of weeds or aquatic macrophytes by limiting light penetration. As a consequence, the Robe Lake system exchanged a periodic siltation/flooding problem for a major warming, weed enhancement, along with the potential of a winter fish kill, problem. Literally the lake was dying and had become totally unusable.

Subsequent to the publishing of our findings, the City of Valdez has implemented and funded ($200,000) the recommendations in our report. First, they have purchased an aquatic macrophyte (weed) harvester which is now operating to clear the lake. Second, and more importantly for the long term, the city funded a rediversion effort to bring controlled quantities of glacial water back into the lake.

EVALUATION

Chilkat Lake Description

Chilkat (59° 22'N, 135° 56'W) is a fairly large 984.2 ha (2,432 acre) clear water lake with a mean depth of 32.5 m and a volume of 319.4 million m^3. The lake lies at an elevation of 53 m, and is located 137 km northwest of the city of Juneau while the lake outlet lies 30 km northwest of the city of Haines (Figure 1). Precipitation is estimated to average about 165 cm/yr (65 inches) over a 105.1 km^2 (40.6 mi) watershed which results in a water residence time of 2.5 yr. The 1.6 km (1 mi) long outlet stream flows through lowlands and drops about 6 m in elevation before draining into the Tsirku River.

The fishery resources of Chilkat Lake includes anadromous and resident (Kokanee) sockeye salmon (*Oncorhynchus nerka*), coho salmon (*Oncorhynchus kisutch*), cutthroat trout (*Salmo clarki*), Dolly Varden (*Salvelinus malma*), whitefish, threespine stickleback (*Gasterosteus aculeatus*), and sculpin (*Cottus* sp.).

The Rearing Environment

If in-lake temperatures, and primary and secondary production patterns of Chilkat Lake are reduced by the introduction of glacial silt (as outlined above), then it would follow that the freshwater growth of rearing sockeye will be retarded. Data characterizing the rearing environment for sockeye are rare, although samples taken in the fall of 1980 did reveal significant numbers of the cladoceran zooplankters *Daphnia* and *Bosmina*. In addition, reported (Bergander 1985) sizes of age 1. smolt (~98 mm) from Chilkat far exceed that of glacial lakes in general; and, in particular, were larger than smolts (63 mm) from the nearby glacial Chilkoot Lake (Table 2).

Further, a comparison of the scale characteristics from Chilkat and Chilkoot Lakes revealed that the Chilkat sockeye juveniles grew faster in both the first and second years of freshwater growth. Thus, the length of Chilkat Lake smolts is on the upper end of smolt sizes found for some Alaskan lakes compared to just the opposite end of the scale for glacial Chilkoot Lake smolts.

The periodic, minor additions of glacial silt into Chilkat Lake do not appear to be of a magnitude that would cause the lake to approach the 5 NTU turbidity barrier. Overall then, we surmise that the introductions may provide a long term benefit to the basic productivity of this oligotrophic lake. Obviously, a key indicator to approaching this turbidity barrier are periodic turbidity measurements. However, an even better gauge, and even closer in the food chain to the rearing sockeye juveniles, is the species composition of the zooplankton (fish forage). Lake systems, turbid with silt, do not contain cladoceran zooplankters (Edmundson and Koenings 1985b; Koenings et al. 1986) which, in stark contrast, are common to all non-turbid systems (Table 1). Periodic zooplankton samples would reveal any damage to the preferred forage species for rearing sockeye juveniles caused by excessive turbidities. We would urge that both these parameters be followed to insure continued production of sockeye salmon from this system.

Recommendations

1) Quantify the magnitude and the seasonal, and yearly occurrence of glacial water intrusion into Chilkat Lake.

2) Determine the density of stickleback in Chilkat and Chilkoot Lakes as sticklebacks are less abundant in glacial lakes.

3) Gather appropriate in-lake fisheries and limnological information to be able to define and understand the rearing requirements and limitations for sockeye juveniles in both Chilkat and Chilkoot Lakes.

4) If appropriate, make future recommendations concerning both the impact of glacial water influx on the rearing capacity of Chilkat Lake and any rehabilitation/enhancement strategies.

5) Address the concerns that sockeye enhancement may have on the cutthroat trout population as residents of Haines have historically described the cutthroat trout fishing in Chilkat Lake as the best in the area.

REFERENCES

Anonymous. 1960. Fish and Wildlife Resources in relation to the proposed diversion of the Chilkat River. U. S. Fish and Wildlife Service, Juneau, Alaska. 38 p

Bachmann, R. W. 1980. The role of agricultural sediments and chemicals in eutrophication. J. Water Pollution Control Federation. 52:2425-2431.

Bergander, F. A. 1985. Stock assessment and evaluation - Southeast Alaska. Alaska Department of Fish and Game, Technical Data Rep. 142:27 p.

Bishop, D. M. 1984. Written communication. Juneau. 2 p.

Brylinsky, M. and K. H. Mann. 1973. An analysis of factors governing productivity in lakes and reservoirs. Limnol. Oceanogr. 18:1-14.

Burkett, R. D. and J. P. Koenings. 1986. Karluk Lake: The Rubic's Cube for aquatic scientists. Alaska Fish and Game. 18(3):15-16.

Dillon, P. J. and F. H. Rigler. 1974. The phosphorus-chlorophyll a relationship in lakes. Limnol. Oceanogr. 19:767-773.

Dugdale, R. C. and V. A. Dugdale. 1961. Sources of phosphorus and nitrogen for lakes in Afognak Island. Limnol. Oceanog. 6:13-23.

Edmundson, J. A. and J. P. Koenings. 1985. The effects of glacial silt on primary production, through altered light regimes and phosphorus levels in Alaska lakes. pp: 3-20. In: L. P. Dwight (ed.), Resolving Alaska's Water Resources

Conflicts. University of Alaska-Fairbanks, Institute of Water Resources Report 108. 212 p.

Edmundson, J. M. and J. P. Koenings. 1985. The influences of suspended glacial particles on the macro-zooplankton community structure within glacial lakes. pp: 21-36. In: L. P. Dwight (ed.), Resolving Alaska's Water Resources Conflicts. University of Alaska-Fairbanks, Institute of Water Resources Report 108. 212 p.

Eicher, G. J. and G. A. Rounsefell. 1957. Effects of lake fertilization by volcanic activity on abundance of salmon. Limnol. Oceanogr. 2:70-76.

Foerster, R. E. 1968. The sockeye salmon, *Oncorhynchus nerka*. Fish. Res. Board of Can. Bul. 162:422 p.

Hanson, J. M. and W. C. Leggett. 1982. Empirical prediction of fish biomass and yield. Can. J. Fish. and Aquatic Sci. 39:257-263.

Hecky, R. E. 1984. Thermal and optical characteristics of Southern Indian Lake before, during and after impoundment and Churchill River diverson. Can. J. Fish. Aquat. Sci. 41:579-590.

Jones, J. R. and M. V. Hoyer. 1982. Sport fish harvest predicted by summer chlorophyll a concentration in Midwestern lakes and reservoirs. Trans. Amer. Fish. Soc. 111:176-179.

Koenings, J. P., R. D. Burkett, and G. B. Kyle. 1985. Limnological and fisheries evidence for rearing limitation of sockeye production in Crescent Lake, Southcentral Alaska, (1979-1982). Alaska Department of Fish and Game, FRED Technical Report No. 57. 113 p.

Koenings, J. P., R. D. Burkett, G. B. Kyle, J. A. Edmundson, and J. M. Edmundson. 1986. Trophic level responses to glacial meltwater intrusion in Alaskan lakes. pp. 179-194. In: Kane, D. L. (ed.). Symposium: Cold Regions Hydrology (Proceedings). American Water Resources Assoc. Bethesda, MD. USA. 612 p.

Koenings, J. P. and R. D. Burkett. 1987. Population characteristics of sockeye salmon (*Oncorhynchus nerka*) smolts relative to temperature regimes, euphotic volume, fry density, and forage base within Alaskan Lakes, P. 216-234. In: H. D. Smith, L. Margoles, and C. C. Wood [ed.]. Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96.

Koenings, J. P., J. A. Edmundson, G. B. Kyle, and J. M. Edmundson. 1987a. Limnology Field and Laboratory Manual: Methods of assessing aquatic production. Alaska Department of Fish and Game, FRED Division Technical Report No. 71. 212 p.

Koenings, J. P., D. Barto, and G. Perkins. 1987b. Assessing the water quality of Robe Lake, Alaska, 1981-1982. Alaska Department of Fish and Game, FRED Division Technical Report Series 77:82 p.

Kuenzler, E. J., D. W. Stanley, and J. P. Koenings. 1979. Nutrient kinetics of phytoplankton in the Pamlico River, North Carolina. Water Resources Institute, Research Report No. 139. 163 p.

Lloyd, D. S., J. P. Koenings, and J. D. Laperriere. 1987. Effects of turbidity in freshwaters of Alaska. North Amer. J. of Fisheries Management. 7:18-33.

Mayo, L. R. 1986. Annual runoff rate from glaciers in Alaska: A model using the altitude of glacier mass balance equilibrium. p. 509-517. In: D. L. Kane [ed.], Proceedings: Cold Regions Hydrology Symposium American Water Resources Assoc. Bethesda, Maryland.

McConnell, W. J., S. Lewis, and J. E. Olson. 1977. Gross photosynthesis as a estimator of potential fish production. Trans. Amer. Fish. Soc. 106:417-423.

Nelson, P. R. 1958. Relationship between rate of photosynthesis and growth of juvenile red salmon. Science. 128:205-206.

Oglesby, R. T. 1977. Phytoplankton summer standing crop and annual productivity as functions of phosphorus loading and various physical factors. J. Fish. Res. Board Can. 34:2255-2270.

Schindler, D. W. 1978. Factors regulating phytoplankton production and standing crop in the world's freshwaters. Limnol. Oceanogr. 23:478-486.

Smith, E. A. and C. I. Mayfield. 1977. Effects of phosphorus from apatite on development of freshwater communities. J. Fish. Res. Board Can. 34:24-5-2409.

Smith, V. A. 1979. Nutrient dependence of primary productivity in lakes. Limnol. Oceanogr. 24:1051-1064.

Vollenweider, R. A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrabiol. 33:53-83.

Wang, W. C. 1974. Absorption of phosphate by river particulate matter. Water Res. Bull. 10:662-671.